BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B69 12066

SUBJECT: Comparative Analysis of Life Support Systems for Emergency Return During Lunar EVA - Case 320

DATE: December 19, 1969

FROM: T. A. Bottomley

ABSTRACT

Following the October 31, 1969 CCB meeting it was proposed that a) procurement of the Secondary Life Support System (SLSS) be cancelled and b) that consideration be given to modifying the -7 PLSS to accommodate two crewmen at one time (buddy system) for use in an emergency mode.

This memorandum covers an analysis of the buddy system PLSS and other potential configurations based on performance requirements for carbon dioxide, humidity and thermal control during lunar EVA emergency return to the LM. The various configurations are compared on the bases of return distance capability and weight penalty.

Based on the results of this study, it is concluded that two configurations are logical candidates for emergency use in LEP.

a) -7 PLSS/SLSS, and

b) buddy -7 PLSS/OPS

Both configurations provide about the same return distance capability but the buddy -7 PLSS/OPS combination results in 30 and 40 pounds less weight carried to and from the moon, respectively.

Disadvantages of the buddy arrangement include vacuum transfer on the lunar surface and reduction in orbital science EVA capability if the OPS is used as the primary life support system. In addition, emergency walk-back capability is limited to about one hour (two kilometers) because of the non-linear performance characteristics of the liquid cooling loop and carbon dioxide control cannister.

Other operational and engineering unknowns argue for deferment of any decision to select the buddy configuration for LEP. Walk-back rates, fan and pump performance, and inter-connection arrangements are representative of areas which require further analysis.

(NASA-CR-107807) COMPARATIVE ANALYSIS OF LIFE SUPPORT SYSTEMS FOR EMERGENCY RETURN DURING LUNAR EVA (Bellcomm, Inc.) 19 p

N79-73077

Unclas
00/54 11686

FF No. 602
CR-107807
(NASA CR OR TMX OR AD NUMBER) (CATEGORY)
[redacted]

BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B69 12066

SUBJECT: Comparative Analysis of Life Support Systems for Emergency Return During Lunar EVA - Case 320

DATE: December 19, 1969

FROM: T. A. Bottomley

MEMORANDUM FOR FILE

1.0 INTRODUCTION

This memorandum evaluates various portable life support configurations, in being or under development, based on their respective capabilities for safe emergency return to the LM during a lunar surface EVA. The bases used for configuration design are performance requirements for carbon dioxide and humidity control in the helmet, and avoidance of excessive body heat storage. The bases used for configuration comparison are maximum return distance capability and system weight.

1.1 Background

During the October 30-31, 1969 Configuration Control Board (CCB) meeting, a total of nine changes to the Secondary Life Support System (SLSS) were submitted for board approval. In general, the proposed changes provided for improved instrumentation and resizing. All changes which required increasing the size of the SLSS were disapproved because of potential impact on LM stowage and interference with LM systems during pre- and post- EVA activities.(1)

Subsequent to the CCB meeting it was recommended that the requirements and capabilities for backup life support systems be reexamined considering a) cancelling procurement of the SLSS and b) providing a buddy system arrangement for backup life support on the -7 Portable Life Support System.

MSC/PD was requested to examine the feasibility of these proposals for review with Dr. Gilruth on November 17, 1969. At MSC's request, an independent review was conducted also by Bellcomm as a check on their results. The Bellcomm findings, expanded to consider other potential candidate configurations, are contained in this report. A summary was sent to C. H. Perrine on November 14, 1969.(2)

2.0 DISCUSSION

Three functionally different systems were evaluated in this study. They were:

a) Closed loop, in which the atmosphere and thermal control loops are reconditioned for recirculation by the life support system.

b) Open loop (purge mode), in which consumables are supplied by the life support system and dumped overboard on a continuous basis.

c) Semi-open loop, in which consumables are supplied by the life support system on a demand rate basis and then dumped overboard.

The various system configurations which were evaluated consist of hardware developed or under development for Apollo, and hardware under development for NASA for possible use in future programs. The latter items, though not yet fabricated in flight-prototype form, have undergone testing which indicates that they are conceptually sound and may be significant improvements in life support systems development.(3)

The Apollo hardware which was evaluated consists of:

a) -7 PLSS - The PLSS is a closed loop system, unmodified, or modified to accommodate two men in an emergency (i.e. buddy system arrangement).

b) Oxygen Purge System (OPS) - The OPS may be unmodified or modified to provide various oxygen flow rates as required. OPS operation is either open loop or semi-open loop when mated with other assemblies in a new configuration.

Open loop operation of the OPS at reduced flow rates will require modification of the purge valve and, possibly, of the oxygen regulator assembly to avoid overpressurizing the suit. Use of the OPS with the breathing vest discussed below (i.e., semi-open loop) may require modifications to both the OPS and the EMU. For example, the breathing vest oro-nasal ports attach to the communications cap and accommodate the microphones. As presently configured, this apparatus interferes with the helmet feed port.[3]

It is assumed in this analysis that the -7 PLSS with the buddy system is arranged so that, in event of a PLSS failure, the two crewmen will be connected in parallel on the good unit's atmosphere revitalization loop and liquid cooling loop. Serial arrangements are possible and may be implemented to minimize hardware changes. Connection of the crewmen in series on one or both loops, however, will require that PLSS performance capability be reviewed with respect to the worst case (downstream) astronaut.

Future hardware considered in this study consists of:

a) Breathing Vest (BV) - The breathing vest, used in conjunction with an oxygen supply (e.g. OPS), provides for semi-open loop operation by supplying oxygen on demand with each inspiration. The device collects the breathed air as it is expired and dumps it overboard when refilled from the oxygen supply.

b) Evaporative Cooling Garment System (ECGS) - The ECGS configuration evaluated here is designed for wear over the Liquid Cooling Garment (LCG). It provides emergency cooling by evaporating self-contained water to space (open loop) in event of primary system failure.

While these future items were included for study purposes, it must be noted that early development testing is still in progress. At the present level of effort it is not considered likely that flight hardware can be made available for the LEP missions. Accordingly, a decision to incorporate this hardware into EVA life support systems for lunar exploration increases the risk of program slippage.

2.1 Performance Requirements

The functions examined in making this analysis of systems performance are provided by the atmosphere control and thermal control loops. The functional requirements and performance limits are based on current Apollo specifications covering emergency operation during EVA.[4] Paraphrased, they are as follows:

a) Atmosphere control - Provides adequate oxygen flow to limit CO_2 concentration in the oro-nasal area of the helmet to not more than 15mm Hg absolute pressure and to preclude helmet fogging.

b) Thermal control - Provide adequate cooling (gaseous or liquid) to limit total heat storage to not more than 400 Btu.

The metabolic rates assumed in this analysis are the A7L suit baseline values established for LEP.(5) They are as follows:

a)	Riding	- 700 Btu/hr
b)	Walking (emergency return)	- 1400 Btu/hr
c)	Ingress, egress and science	- 1100 Btu/hr for 1.5 hours

Total travel time is 3.5 hours nominal and 4.5 hours in an emergency based on time-in-suit limits of 5 hours (nominal) and 6 hours (emergency). Maximum return distance is computed for one-half total travel time where the time-in-suit constraint applies.

Both the closed loop and open loop systems evaluated herein depend on gaseous ventilitation to washout CO_2 and humidity from the helmet. The oxygen flow rates required to control CO_2 levels to 7.6 and 15mm Hg absolute pressures as a function of metabolic rate are shown on Figure 1. The data of Figure 1 are based on MSC experiments using early Apollo suit ventilating systems.(6) The required flow rates are conservative values as helmet ventilation has since been improved.

Figure 2 shows flow rates required to preclude visor fogging as a function of visor temperature at LEP baseline energy levels. This figure has been constructed from empirical data which show that the amount of expired moisture is inversely proportional to the vapor pressure and total pressure of the inspired air and directly proportional to minute volume (i.e. breathing rate and depth).(7) Since minute volume is linearly related to metabolic rate, moisture input to the helmet can be predicted for the EVA astronaut if his work load and atmospheric environment are known. If inlet conditions are known too, the required flow rate for humidity control can be determined psychometrically. It is assumed in this study that inlet oxygen is dry gas at 60°F and that 100% mixing occurs.

2.2 Closed Loop Operation (Buddy System)

The -7 PLSS provides 6 cfm (∿7 lbs/hr) ventilation flow to the helmet. The temperature of the gas at the PGA inlet is required to be between 35°F and 85°F.[4] Connecting two astronauts to one PLSS reduces the oxygen flow rate to each man to about 3.5 lbs/hr. This rate is adequate to control CO_2 levels in the oro-nasal region below 15mm Hg at 1600 Btu/hr if there is no CO_2 returned from the PLSS. It also is adequate to prevent fogging at visor temperatures near 60°F on riding missions (700 Btu/hr/man) and above 76°F on walking missions (1400 Btu/hr/man).

Two astronauts on one PLSS will double the consumption rates of oxygen and water assuming equal work levels and that the failed PLSS is useless. The effect on the CO_2 absorber (lithium hydroxide) lifetime is much greater. Doubling the metabolic rate from 700 to 1400 Btu/hr reduces LiOH life by a factor of about 3. An increase from 1400 to 2800 Btu/hr reduces LiOH lifetime by a factor greater than 5. Based on currently available information, overall life of the LiOH is about 5 hours at 1400 Btu/hr and about one hour at 2800 Btu/hr.

Inspection of Liquid Cooling Garment (LCG) performance data indicates that the overall system falls behind in removing heat from the man at about 1700 Btu/hr. At 2800 Btu/hr. workload the EVA astronaut will reach the permissable heat storage limit (400 Btu) in about one hour. Assuming that the performance capability of two liquid cooling loops on one PLSS is halved, extrapolation of the data suggests that thermal control will be adequate for emergency return on a riding mission (i.e. 1400 Btu/hr input) but may not be adequate for return times exceeding one hour on a walking mission (i.e. 2800 Btu/hr input).

In summary, it is concluded that provision of a buddy arrangement on the -7 PLSS:

a) Will provide for safe emergency return of the astronauts on riding missions without exceeding emergency limits for CO_2 control and heat storage. Visor fogging will not be a problem at visor temperatures as low as 60°F.

b) It will not provide the capability for safe return on walking missions if return time exceeds one hour. The limiting factors are LiOH lifetime and heat storage. Visor fogging would be a problem at visor temperatures below 76°F.

It should be noted that use of the buddy PLSS/OPS configuration will probably require making vacuum disconnects, an operational procedure which the crews prefer to avoid. In addition, use of the OPS in place of the SLSS for orbital science EVA may prove feasible only if the OPS is used as a backup to umbilical life support.

2.3 Open Loop Operation (Purge Mode)

Figures 3 and 4 show the total oxygen and flow rates required during walking and riding emergencies if gaseous oxygen only is used in a purge mode to satisfy all functions of atmospheric and thermal control during the return period. The weight of oxygen, and system weight and volume, are shown on the ordinates as functions of return time. The capability of the unmodified OPS is shown on each figure as a point of reference. By comparing the flow rates needed to satisfy each function, it can be seen that heat storage limitations fix the requirements for an oxygen purge system. If thermal control is provided by other means, visor fogging dictates the required flow rates unless visor temperature is maintained above 82°F. At visor temperatures above 82°F, oxygen flow rate is dictated by CO_2 level control requirements.

Figure 5 shows oxygen and water requirements for an open loop configuration in which thermal control during emergencies only is provided by an evaporative cooling garment with a self-contained water supply. Use of this garment with an OPS modified for lower riding or walking ventilating flow rates approximately doubles the return distance capability at the expense of an increase in overall weight (for two men) of about 25 pounds. For the same system weight (53 lbs/man) there is no significant difference between the performance capabilities of the oxygen purge and oxygen purge plus evaporative cooling configurations.

2.4 Semi-Open Loop (Demand Rate Mode)

Figure 6 shows oxygen and water requirements for the same configuration covered in Figure 5 with the addition of a breathing vest to control oxygen consumption to that required for leakage makeup ($\sim$0.0134 lb/hr) and metabolism. The breathing vest traps CO_2 and lung moisture and, therefore, eliminates any need for high washout flow rates. However, it provides very little cooling via respiratory heat exchange only. Heat lost to the gas via convection and evaporation modes is minimal. As a result, water requirements for thermal control must be increased to avoid exceeding permissable heat storage limits.

Comparison of Figure 6 with Figure 5 indicates increases in return time capability of about 300% walking and 50% riding for this configuration with added weight penalties of only 4 and 2 pounds respectively. For the riding case, the 50% gain is obtainable only if the current 6-hour time-in-suit limit is waived. Imposition of this constraint reduces riding time gain with the breathing vest to about 20%.

3.0 CONFIGURATION COMPARISONS

The return distance capabilities for the various configurations evaluated in this study, in addition to the currently proposed -7 PLSS and SLSS, are listed in Table I. Comparison of these results show that the -7 PLSS/SLSS combination is the best choice to obtain maximum range during lunar surface operations in LEP. (The walk-back distance of 9 kilometers for the OPS+BV+ECGS is artificial since maximum distance on walking traverses will be constrained to 5.4 kilometers by the PLSS consumables required for nominal EVA's).

Table II is a comparison of the various configuration in terms of radius factors, estimated weights and weight increments. Radius factor and weight increments in this table are based on the -7 PLSS/OPS configuration. Radius factor is the ratio of return distance for a given configuration to walk-back distance on the OPS. The baseline weight of the combination is 135 pounds.

Other configurations also have been added to Table II. One of these, the Optimized Life Support System (OPLSS) is presently under development by the AiResearch Corporation. A preliminary design review of this system is planned for December 9-10, 1969.

From Table II, it can be seen that the currently planned -7 PLSS/SLSS, though most desirable for return capability, is the least desirable choice from a weight standpoint. Most desirable, in terms of both return distance capability and weight savings are the -7 PLSS/OPS with the buddy modification, or the OPLSS. As mentioned before, procurement of items still being developed (e.g. the OPLSS) carries increased risk of program slippage. In addition, one or both OPLSS's, because backup capability is integral to the unit, may have to be carried during lunar ascent in case they are needed for transfer to the CM. This would result in an excessive ascent stage weight penalty (280 lbs vs. 80 lbs for the OPS and 280 lbs vs. 120 lbs for the SLSS).

4.0 CONCLUSIONS

Based on the results of this study, two life support systems configurations are logical candidates for emergency use during lunar EVA in LEP. These configurations are:

1) -7 PLSS/SLSS
2) -7 PLSS (buddy system)/OPS

Both systems will provide approximately the same return distance capability. However, the buddy PLSS/OPS combination will result in a reduction of about 30 pounds in EMU weight carried to, and 40 lbs returned from the lunar surface.

The disadvantages of the buddy PLSS/OPS configuration are:

a) vacuum disconnect is required to change to buddy mode,

b) impacts orbital science EVA capability unless the OPS is used as a backup to umbilical life support,and

c) will not provide emergency walk-back capability for more than one-hour due to non-linear performance characteristics of the thermal and carbon dioxide control subsystems.

There may be other operational constraints and engineering problems, not treated in this study, which preclude selection of the buddy configuration. For example, walk-back velocity and energy cost in the buddy mode are not known; fan and pump performance will require analysis; and, suit and back pack connecting arrangements must be evaluated.

Other systems which are still in various stages of development look very promising for extended EVA use. In particular, the breathing vest and evaporative cooling garment appear to be breakthroughs in life support systems development. Use of these elements in this analysis in conjunction with off-the-shelf hardware results in a suboptimum configuration. Imposition of current operational constraints (e.g. 6-hour time-in-suit limit), however, largely precludes realizing gains provided by these units which are most significant at high workloads or as EVA time is increased. The data in this study do suggest that the breathing vest and ECGS may be especially desirable during emergencies and during orbital science EVA where workload may be quite high and consumables life must be extended with minimum design impact on current life support configurations.

T. A. Bottomley

2032-TAB-tla T. A. Bottomley

Attachments

REFERENCES

1. Perrine, C. H. (MSC/PD), Informal Communication on November 10, 1969.

2. Bottomley, T. A., Working Papers data faxed to C. H. Perrine, November 14, 1969.

3. McMann, J. (MSC/EC), Informal Communication on November 10, 1969.

4. Master End Item Specification CSD-A-096, (Revision A) Performance/Design and Product Configuration Requirements, Extravehicular Mobility Unit, MSC, Houston, Texas, May 7, 1968.

5. Bottomley, T. A., Definition of Energy Costs for Lunar Surface EVA, Bellcomm Memorandum for File B69 09027, September 8, 1969.

6. Michel, E. L., Sharma, H. S. and Heyer, R. E., Carbon Dioxide Buildup Characteristics in Space Suits, NASA MSC Report to Aerospace Medical Association Meeting, Bal Harbor, Fla., May 6-9, 1968. Aerospace Medicine 40:8, August, 1969.

7. Wortz, E. C. et al, Reduced Barametric Pressure and Respiratory Water Loss, SAM-TR-66-4, School of Aerospace Medicine Brooks AFB, Texas, 1966.

8. Roth, E. M., Section 11 - Inert Gas in "Compendium of Human Responses to the Aerospace Environment", NASA CR-1205 (III) Washington, D. C., November, 1968.

TABLE 1

MAXIMUM RETURN RADIUS CAPABILITY DURING LUNAR EVA

A7L SUIT/-7 PLSS

MOBILITY MODE	WALK	RIDE			
VELOCITY (KM/HR)	4	5	10		
METABOLIC RATE (BTU/HR)	1625/1400 (1)	700	700		
CONFIGURATION	DISTANCE (KM)			CONSTRAINTS	MODE
-7 PLSS	5.4 (2)	8.8/11.3 (3)	17.5/22.5 (3)	Walk-Consumables Ride-Time In Suit	Closed Loop
-7 PLSS (BUDDY SYSTEM)	3.9	10.3	20.7	Walk Only-LiOH & Heat Storage	Closed Loop
SLSS	6.1	11.3(15.2)*	22.5(30.4)*	6 Hr Time-In-Suit *H_2O Supply)	Closed Loop
OPS (5.2 LBS O_2 USABLE)	1.6	2.0	4.0	O_2 Supply	8 lbs/hr
OPS (MODIFIED FLOW) (4)	2.1	5.2	10.3	Heat Storage	6.7 lbs/hr-(walk) 4.0 lbs/hr-(ride)
OPS (MOD. FLOW & ECGS) (5)	3.2	9.4	18.7	Visor Fog Temp	5.4 lbs/hr-(walk) 2.4 lbs/hr-(ride)
OPS (B V & ECGS) (6)	9	11.3(13.3)*	22.5(26.5)*	6 Hr Suit Limit *(O_2 Supply)	1.8 lbs/hr
OPS & ROVER OPS (1 for 2 MEN MOD. FLOW)	1.6	5.3	10.5	O_2 Supply	8 lbs/hr & 4 lbs/hr

(1) Nominal/Emergency
(2) Limited by Nominal Metabolic Rate
(3) 5/6 Hr Time-In-Suit Limit
(4) Modification of Purge Valve Required
(5) EVCG = Evaporative Cooling Garment Sys w/Integral Stored H_2O (2.5 to 3.5 lbs req'd)
(6) BV = Breathing Vest (Extends O_2 Supply Up To Factor of 4)

TABLE II

COMPARISON OF LIFE SUPPORT SYSTEMS CONFIGURATIONS
FOR EMERGENCY RETURN DURING LUNAR EVA
A7L SUIT/-7 PLSS

CONFIGURATION	MODE	RADIUS FACTOR (1)		CONSTRAINT	EST'D WT. (LBS) (1MAN)			ΔWT (LBS) (1)	EARLIEST EFFECTIVITY
		WALK	RIDE (2)		O_2	H_2O	Sys.	(2Men)	
OPS	OPEN LOOP	1.0	1.25/2.5	O_2 SUPPLY	5.2	-	40	0	NOW
OPS(MOD.FLOW)	OPEN LOOP	1.3	3.25/6.5	HEAT STOR.	5.2	-	40	0	APOLLO 14
OPS(MOD)+ECGS*	OPEN LOOP	2.0	5.9/1.8	O_2 SUPPLY	5.2	1 (MAX)	[52]	[24]	?
OPS+BV*+ECGS*	SEMI-OPEN LP	5.6	7.1/14 8.3/16.5	SUIT TIME O_2 SUPPLY	5.2	3 (MAX)	[55]	[30]	?
OPS+ROVER OPS (1 for 2 MEN-MOD.)	OPEN LOOP	1.0	3.3/6.6	O_2 SUPPLY	7.8	-	[60]	[40]	APOLLO 16
-7 PLSS(BUDDY SYS)	CLOSED LP (3)	2.4	6.5/13	LiOH, O_2+H_2O	(1.5)	10.8	[100]	[10]	APOLLO 16
OPS+ -7 PLSS (BUDDY SYS)	CL/OP LP	3.4	7.7/15.4	HEAT STOR.	(6.7)	10.8	[140]	[10]	APOLLO 16
OPLSS	SEMI-OPEN LP (4)	3.7	4.7/9.4	O_2 SUPPLY	~6.5 (5)	12.8 (6)	[140]	[10]	APOLLO 17
SLSS	CLOSED LP	3.8	7.1/14 9.5/19	SUIT TIME H_2O SUPPLY	0.52	3	60	40	APOLLO 16

* ECGS EVAPORATIVE COOLING GARMENT SYSTEM; BV = BREATHING VEST

(1) BASED ON -7 PLSS/OPS CONFIGURATION (OPS WALK RETURN DIST = 1.6KM; WT=135 LBS/MAN)

(2) RIDING AT 5/10 KM/HR

(3) RETURN DISTANCE ASSUMES OPS NOT USED

(4) WORST CASE MODE - FAN OR POWER FAILURE

(5) 2.2 LBS (PRIM)+4.3 LBS(SEC)

(6) CHARGED H_2O; SUPPLEMENTED BY RECOVERY FROM MAN

[ ] = ESTIMATED

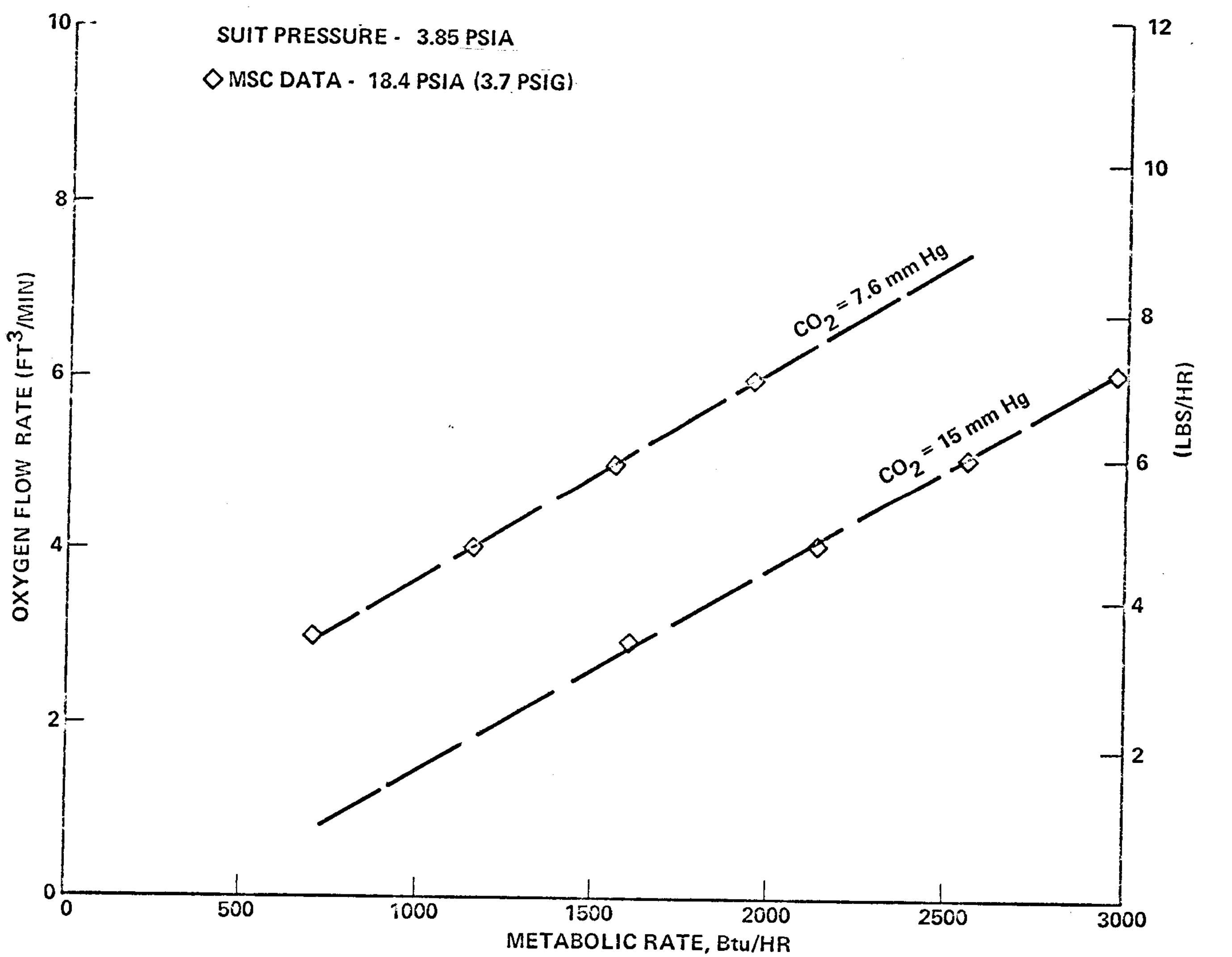

FIGURE 1 - FLOW RATE OF VENTILATING OXYGEN REQUIRED FOR CO_2 CONTROL IN THE ORO–NASAL REGION OF THE HELMET

FROM DATA OF MICHEL et al 6)

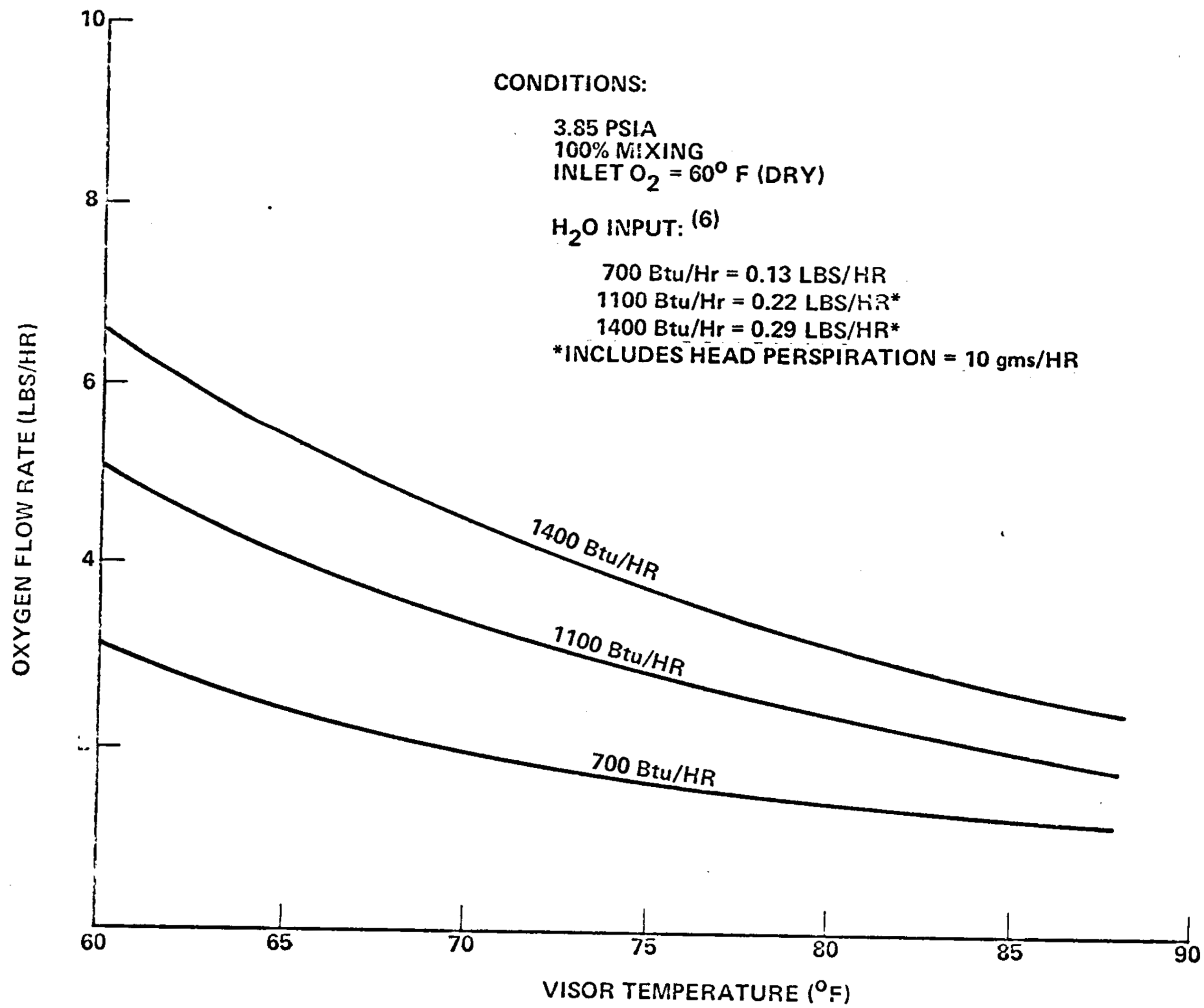

FIGURE 2 - ESTIMATED MINIMUM HELMET VENTILATION RATE REQUIRED TO AVOID VISOR FOGGING

FROM WORTZ et al—SAM TR—66—4 (7)

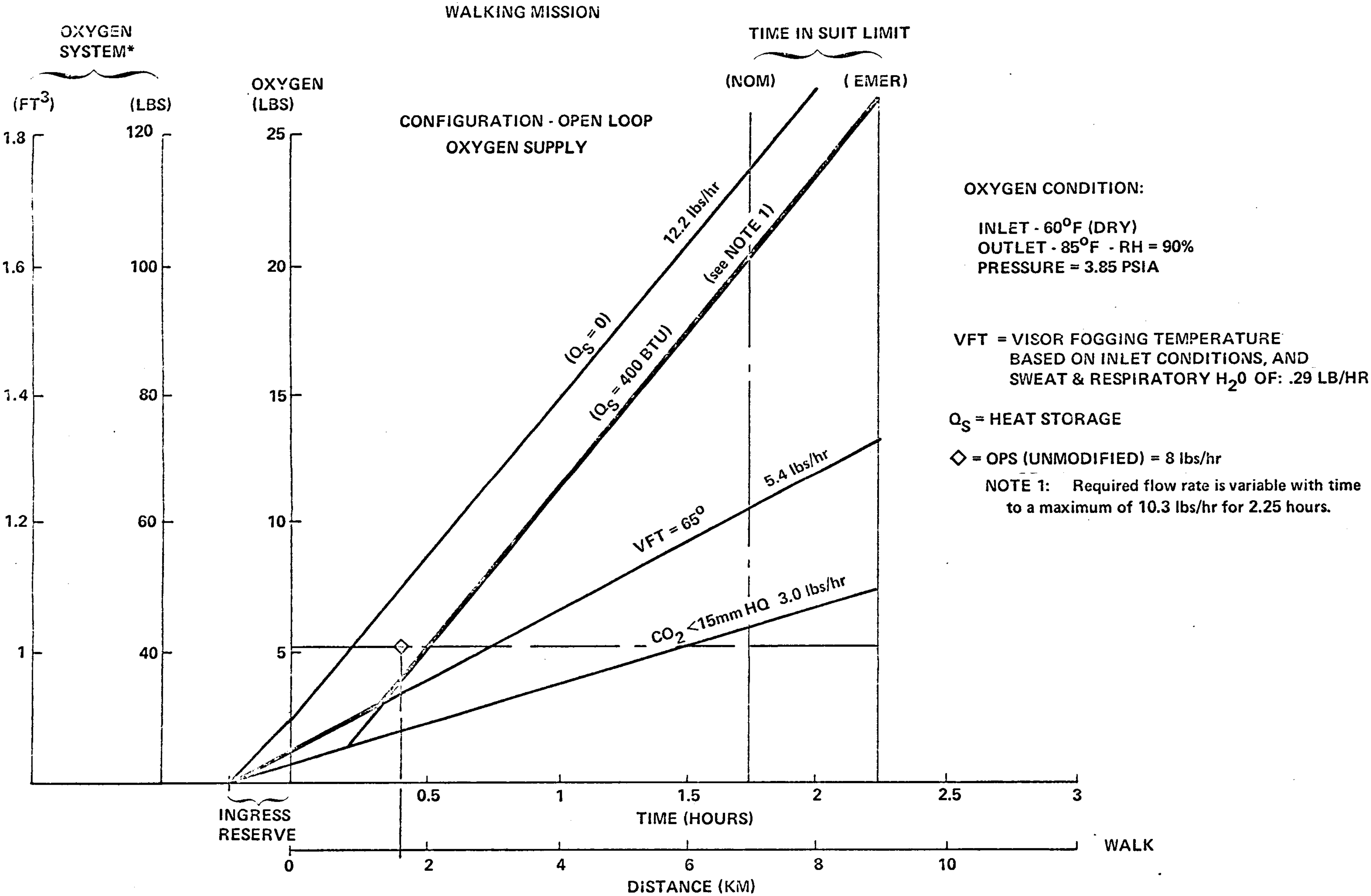

FIGURE 3 - OXYGEN REQUIRED FOR EMERGENCY RETURN DURING LUNAR EVA

*ASSUMES USE OF SPHERICAL SAE 4340 STEEL TANKS AT 6000 PSIA (WT/WG = 4 , VT/WG = 0.04 , F.S. = 2) FROM ROTH (8)

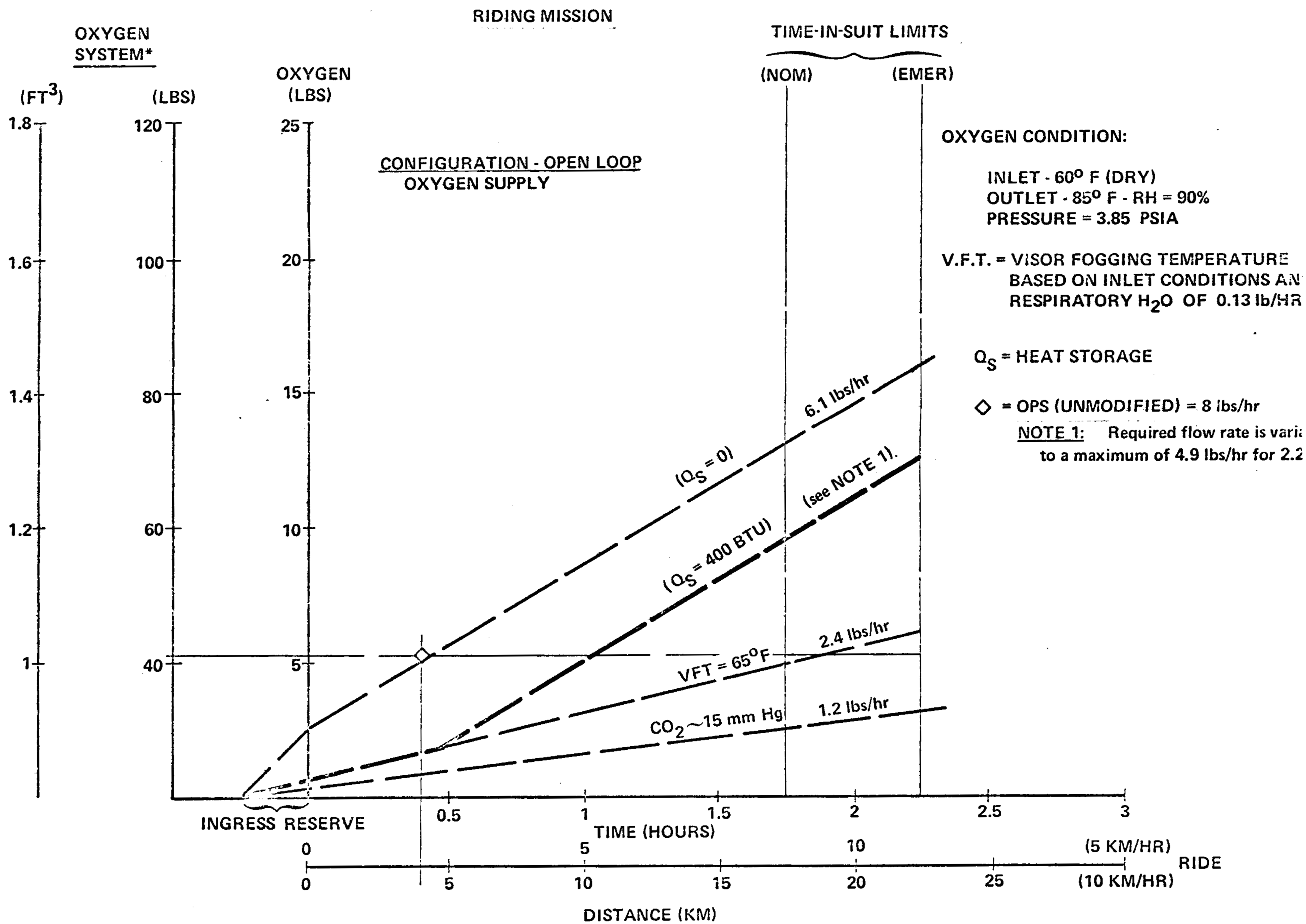

FIGURE 4 - OXYGEN REQUIRED FOR EMERGENCY RETURN DURING LUNAR EVA

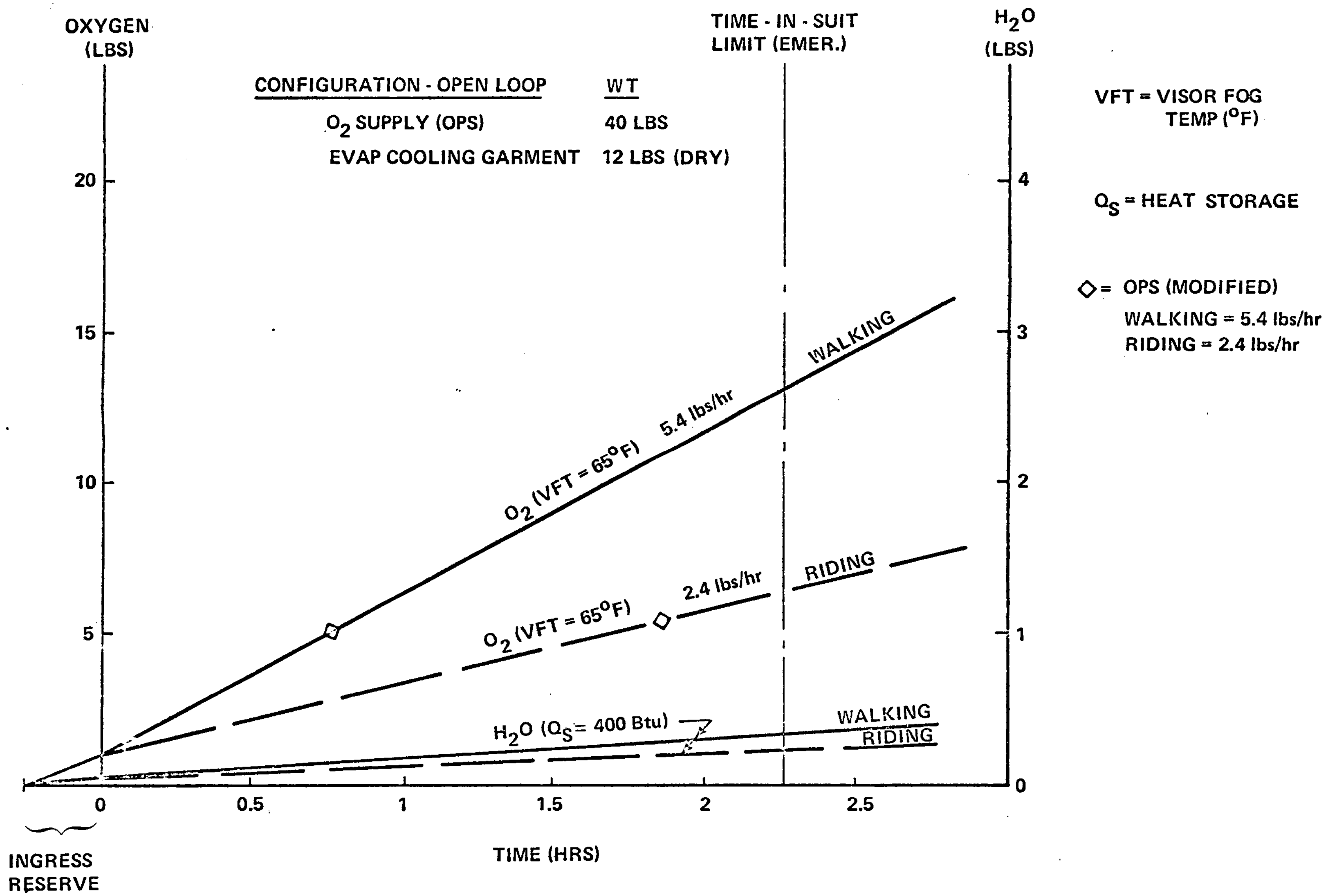

FIGURE 5 - OXYGEN & WATER REQUIREMENTS FOR EMERGENCY RETURN DURING LUNAR EVA

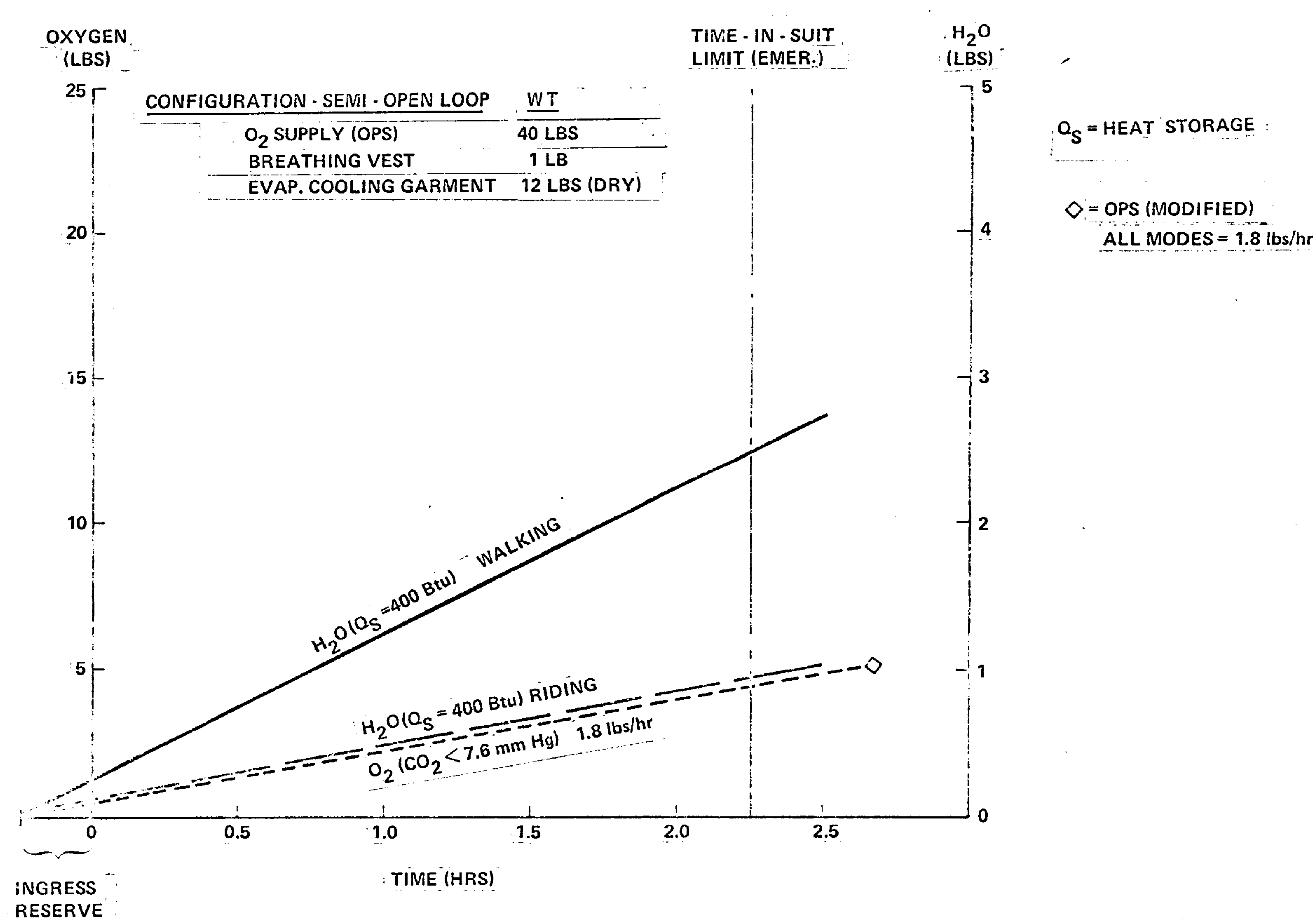

FIGURE 6 - OXYGEN & WATER REQUIREMENTS FOR EMERGENCY RETURN DURING LUNAR EVA

BELLCOMM, INC.

Subject: Comparative Analysis of Life Support Systems for Emergency Return During Lunar EVA - Case 320

From: T. A. Bottomley

Distribution List

NASA Headquarters

M. Behun/MAT
F. B. Benjamin/MM
C. C. Gay/MAT
R. R. Hessberg/MM
J. W. Humphreys/MM
T. A. Keegan/MA-2
C. H. King/MAT
A. F. Phillips/MAT
W. E. Stoney/MA

MSC

L. E. Bell/EC
C. A. Berry/DA
H. R. Hair/DA
W. H. Huffstetler/EC6
G. F. Humbert/DD5
R. S. Johnston/AC
J. P. Loftus/HA
R. E. Mayo/EC6
H. J. McMann/EC6
C. H. Perrine/PD
N. Prince/EC6
R. E. Smylie/EC

Bellcomm, Inc.

G. M. Anderson
A. P. Boysen, Jr.
D. R. Hagner
N. W. Hinners
W. W. Hough
B. T. Howard
D. B. James
A. N. Kontaratos
K. E. Martersteck
J. Z. Menard
P. E. Reynolds
I. M. Ross
J. A. Saxton
L. D. Sortland
R. V. Sperry
W. B. Thompson
R. L. Wagner
M. P. Wilson
Central File
Department 1024 File
Department 2032
Library